Muon Collider & Neutrino Factory Studies

R B Palmer ATF Users 10/18/05

Muon Collaboration

Design Studies

- Muon Collider
  Much smaller than Linear Collider
  Hard Problem - Only conceptual studies done
- Neutrino Factories
  Similar technologies
  Only way to study leptonic CP violation if $\sin^2(2\theta_{13}) < 0.01$
  Detailed Studies including cost and performance

Technology R&D

- Hg Target Experiments
- Cooling Components and MICE Experiment
- 200 MHz SC RF, and FFAG Studies

Collaborators

- US Collaboration $>$ 100 members
  BNL, Cornell, Fermi, LBNL, US Universities (including MSU)
  - 2 Spokespersons: S. Geer, Bob Palmer
  - Project manager: Mike Zisman
  - MCOG Steve Holmes Jim Siegrist, Tom Kirk
  - MUTAC Helen Edwards chair

- European Groups
  CERN, RAL (UK), INFN (Italy), Universities

- Japanese Groups
  KEK, Osaka, other Universities

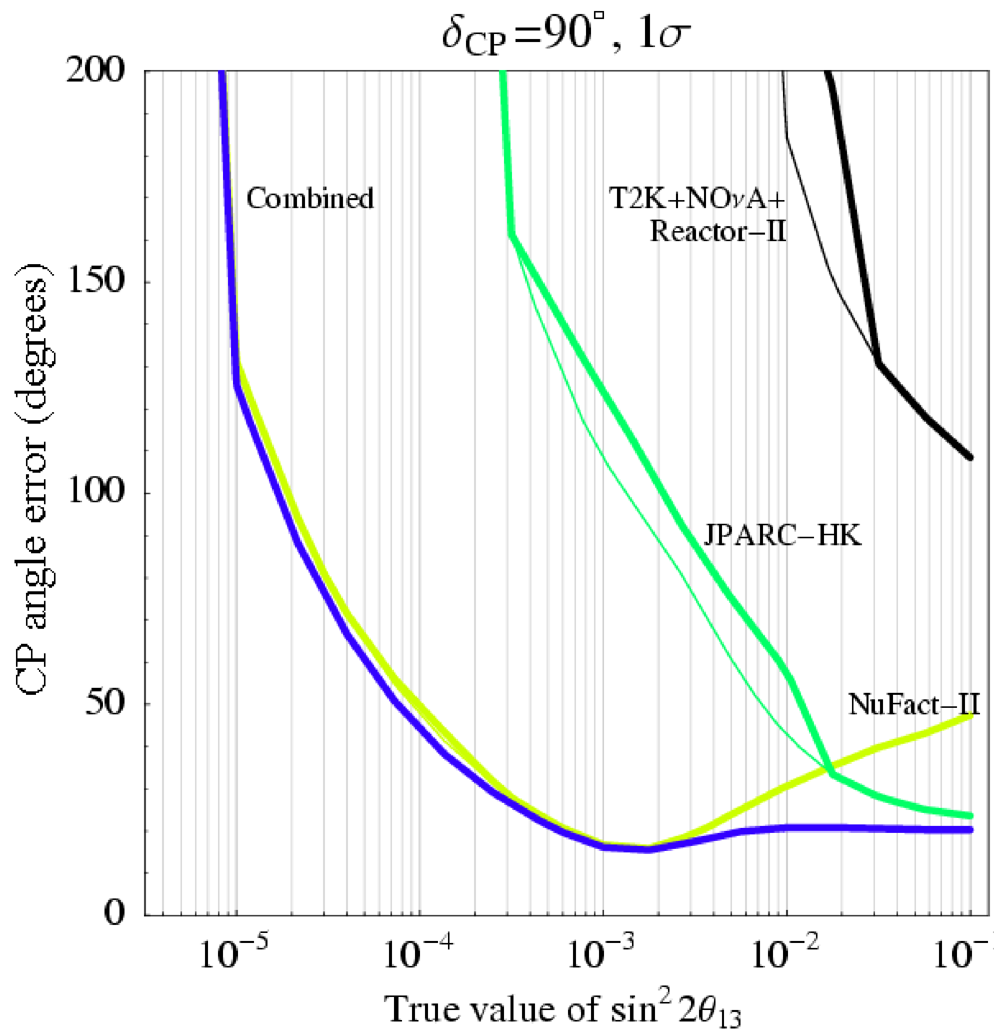
- Russia
  BINP (including Skrinski, who started all this)

NEUTRINO FACTORY

- Uses similar technologies as Collider, but
- Simpler than Collider

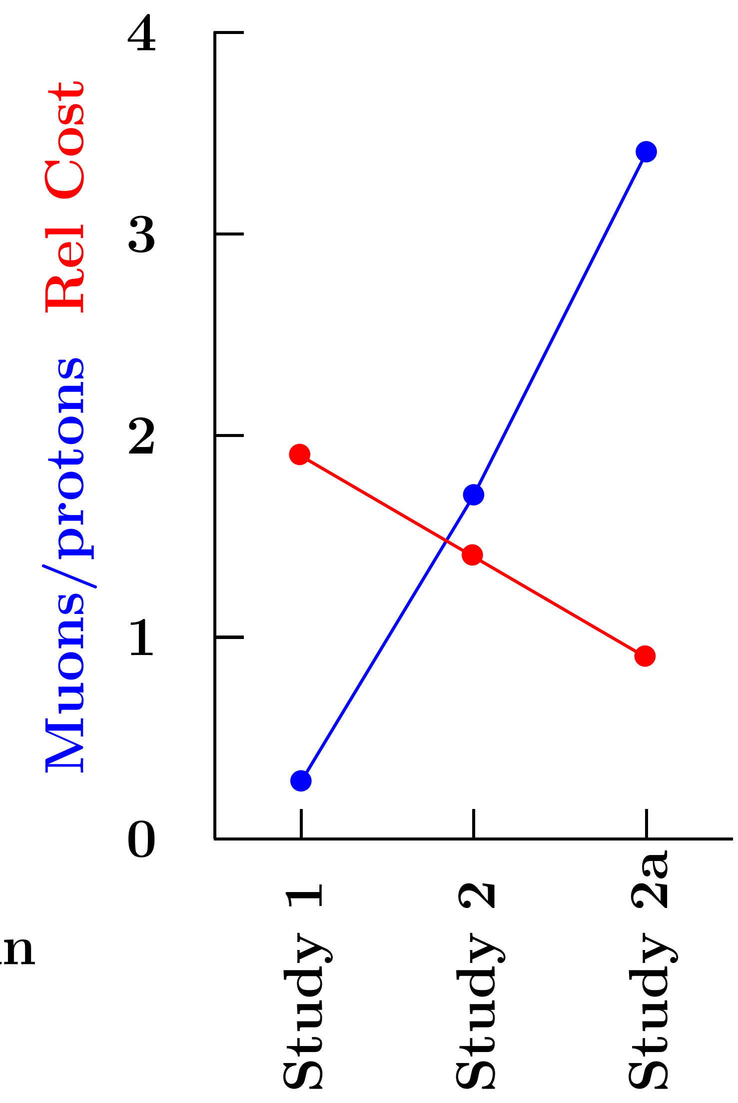
Errors in CP angle δ

- Lower Backgrounds than Conventional Beams
- Only way to study CP Violation if θ_{13} small



US Studies

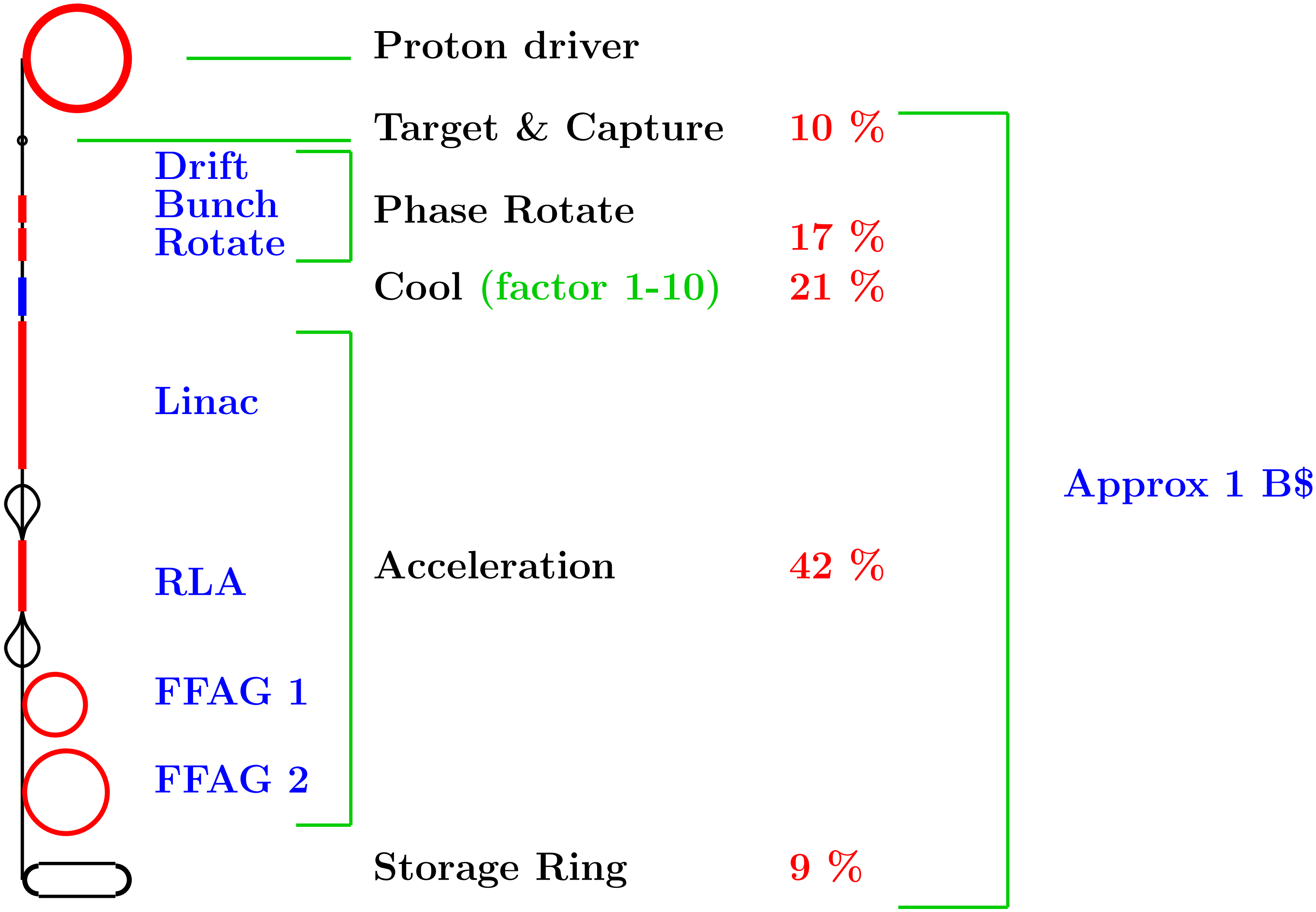
- Feasibility Study 1 (2000)
- Feasibility Study 2 (2002)
- Study 2a for APS (2004)



Great progress
on performance
and Cost

- Parallel studies in Europe and Japan
- Current efforts: A one year International Scoping Study
- Hoping to converge on one scheme

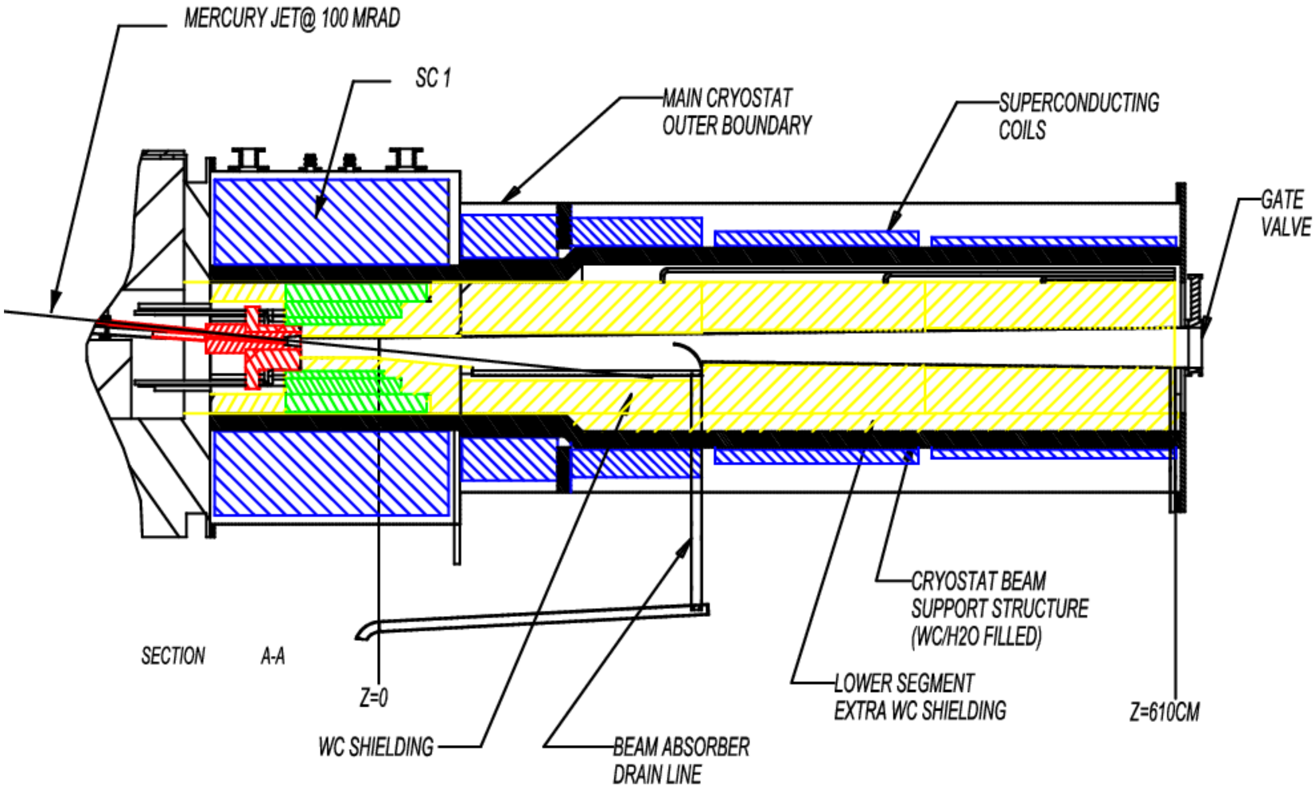
Schematic of Neutrino Factory Study IIa



- Very similar to front end of Collider (but easier)
- Technologies for Factory also apply to Collider

TECHNOLOGIES for Factory or Collider

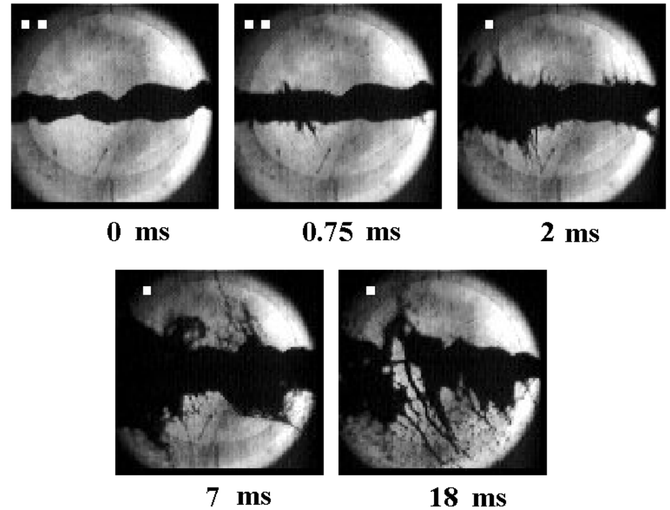
1) Target and Capture



- Liquid mercury Jet 'destroyed' on every pulse
- 20 T Solenoid captures all low momentum pions
- Field subsequently tapers down to approx 2 T
- Target tilted to maximize extraction of pions

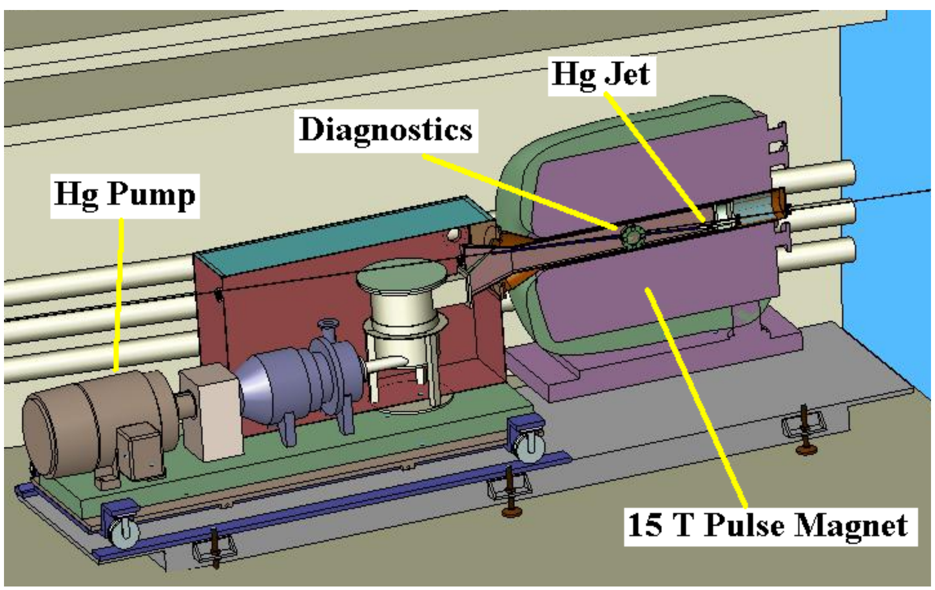
BNL Target Experiment E951

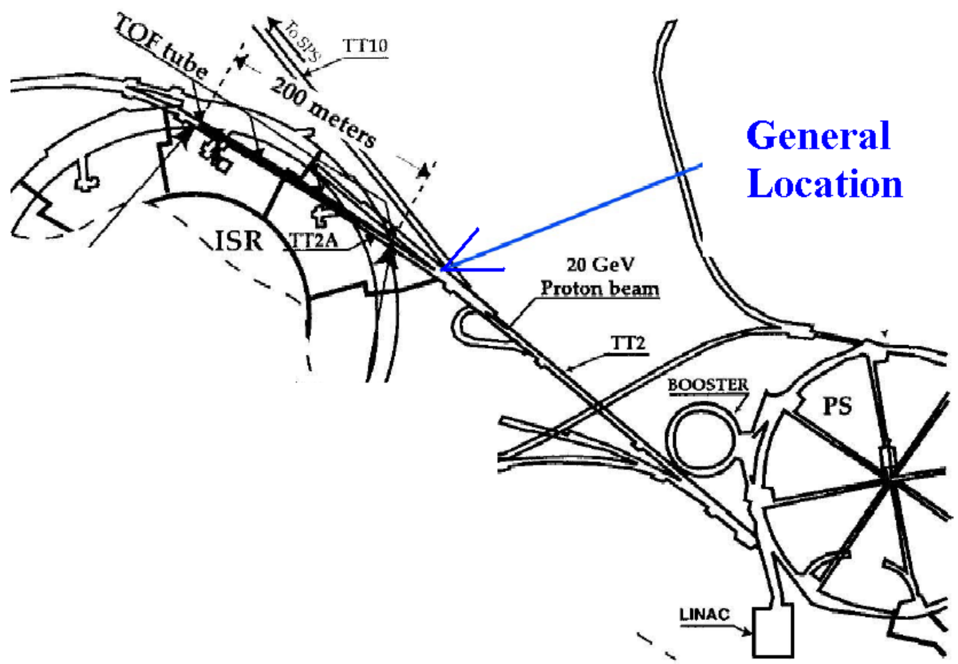
- Single pulse $\boxed{4\ \text{Tp}}$
  But density equiv to 1 MW
- Non-Explosive Dispersion good
- But 4 MW Nu-Factory requires:
  32 Tp/bunch



Approved CERN Experiment MERIT

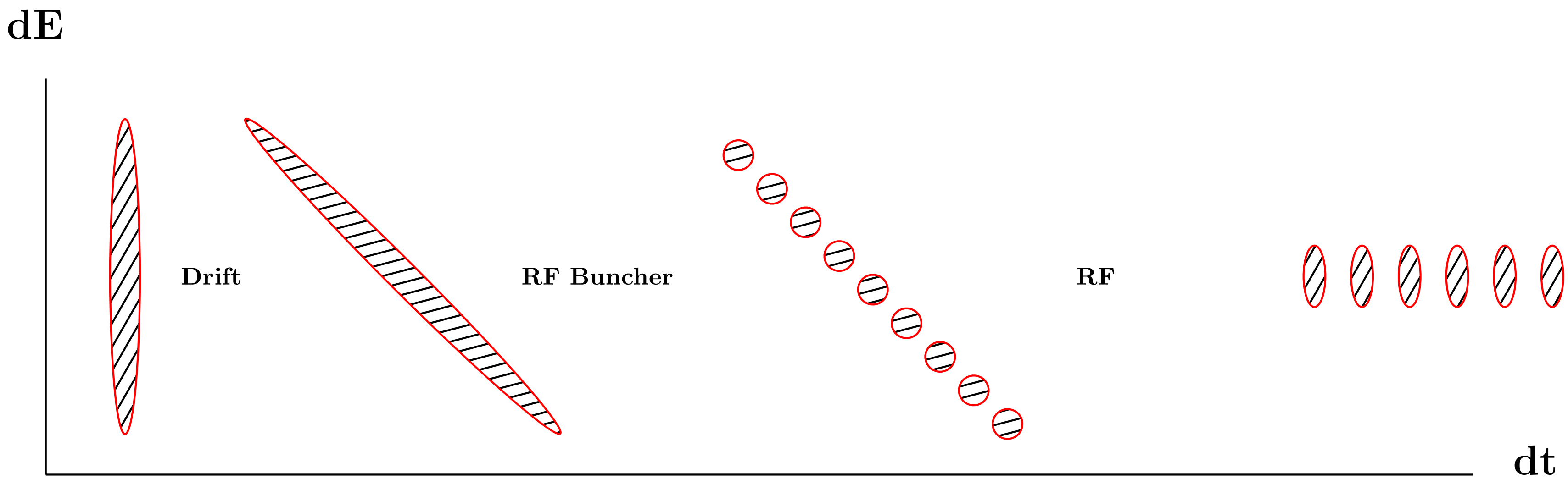
- More intensity $\boxed{32\ \text{Tp}}$ as required for 4 MW
- 15 T pulsed Magnet near completion





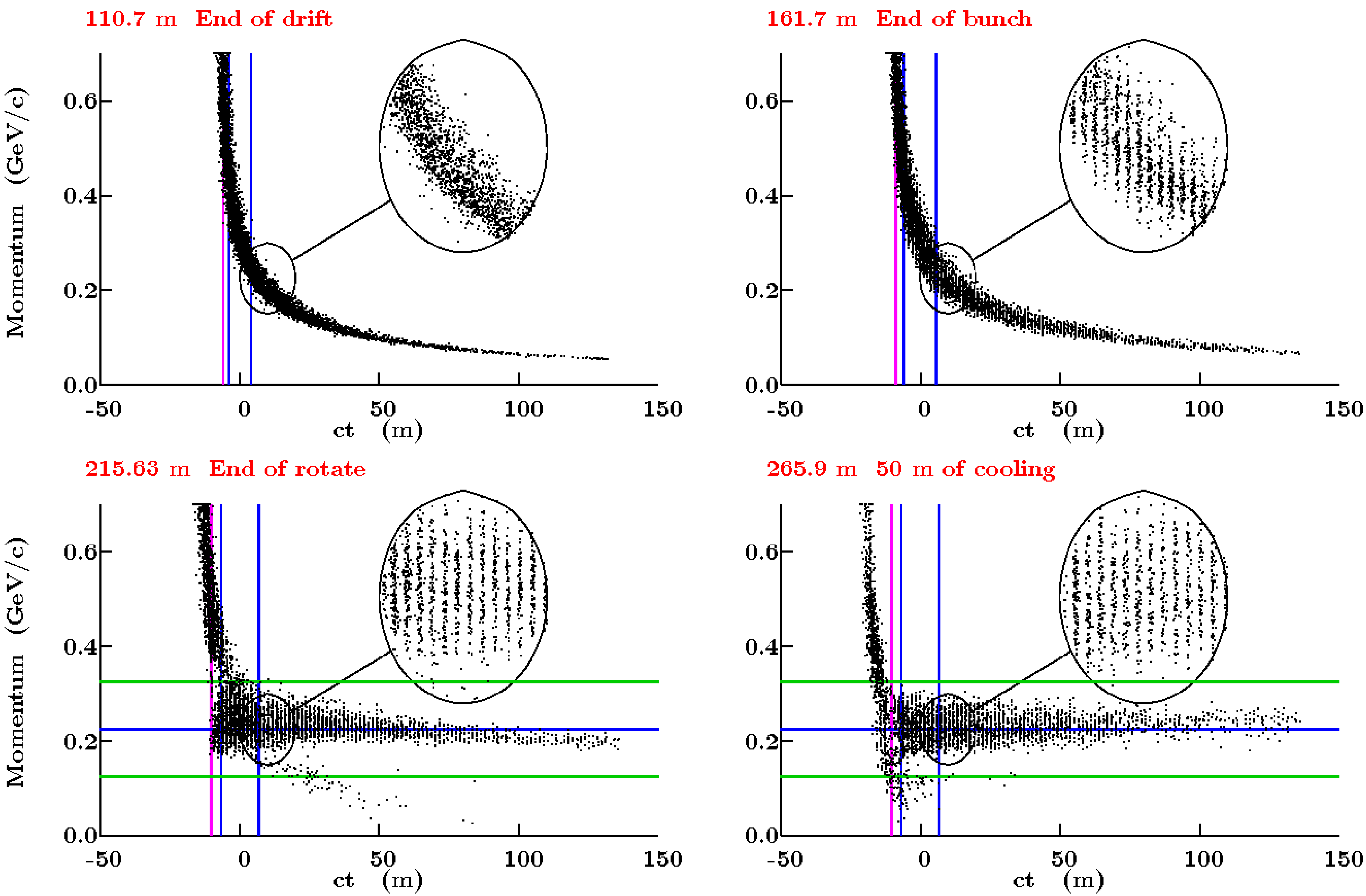
2) Phase Rotation (Reduce dp/p prior to Cooling)

Neuffer's Bunched Beam Rotation with 200 MHz RF



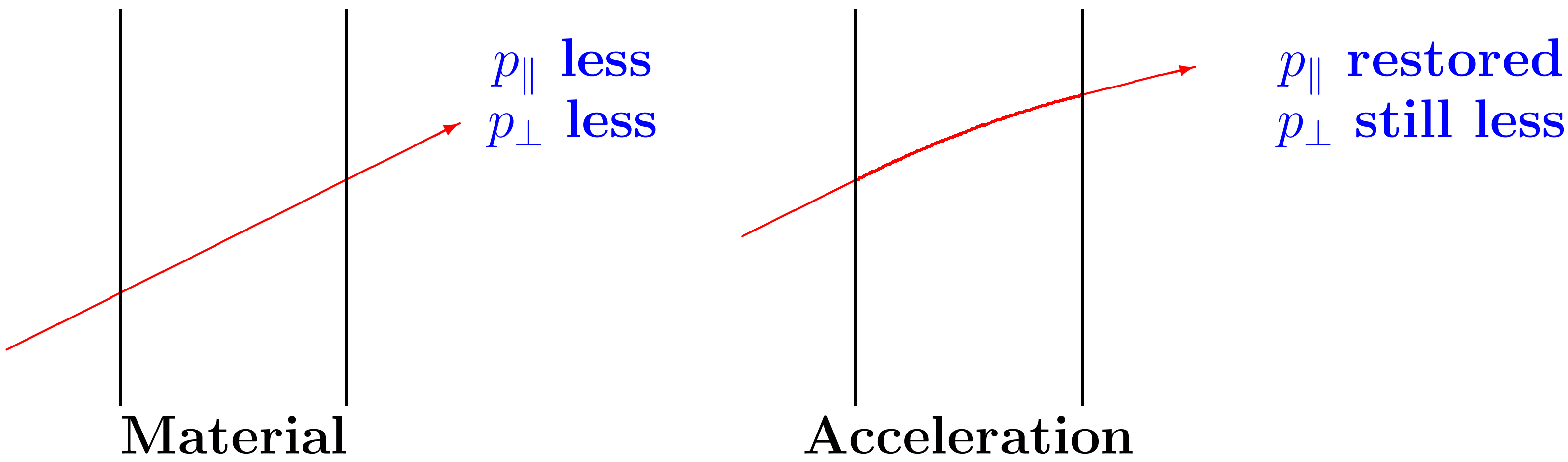
- **RF frequency must vary along bunching channel**
  Because High mom. bunches move faster than lower

Simulation of Phase Rotation



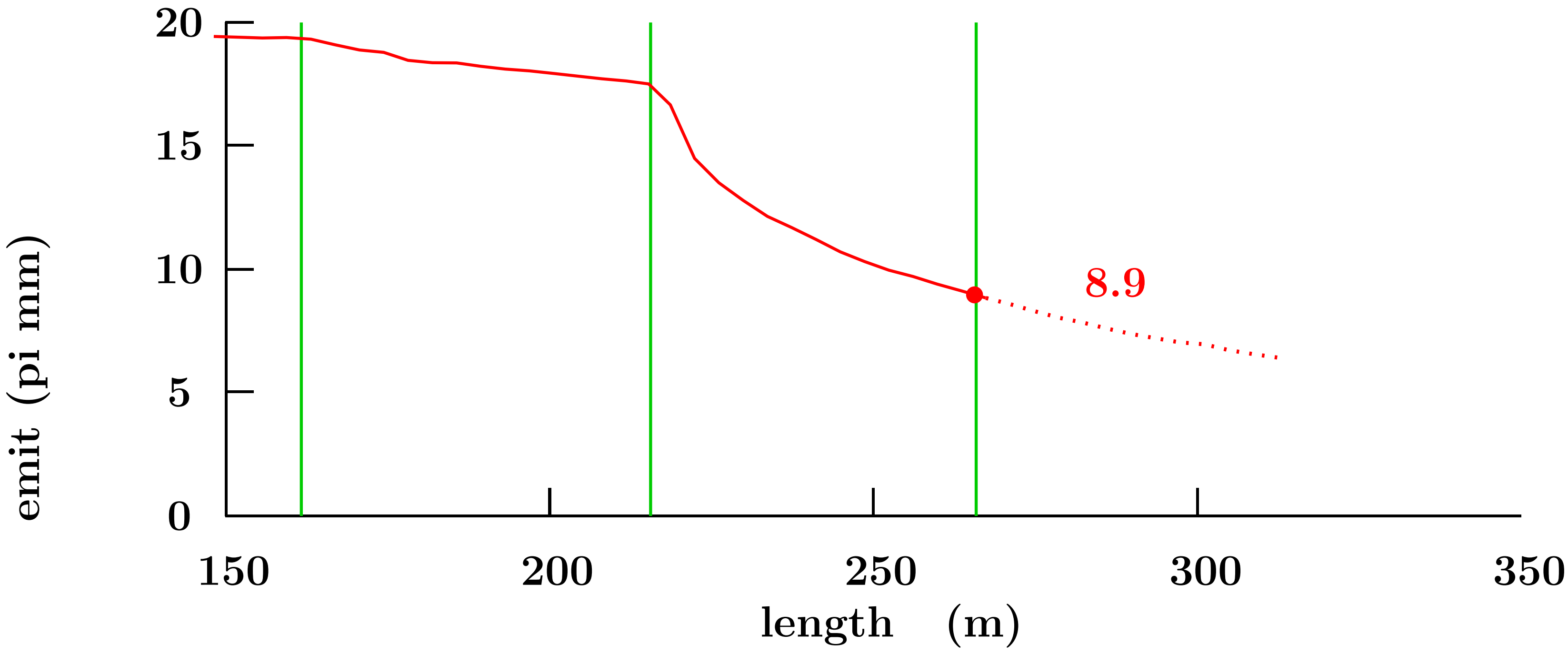
3) Ionization Cooling

Electron, synchrotron, and stochastic cooling all too slow

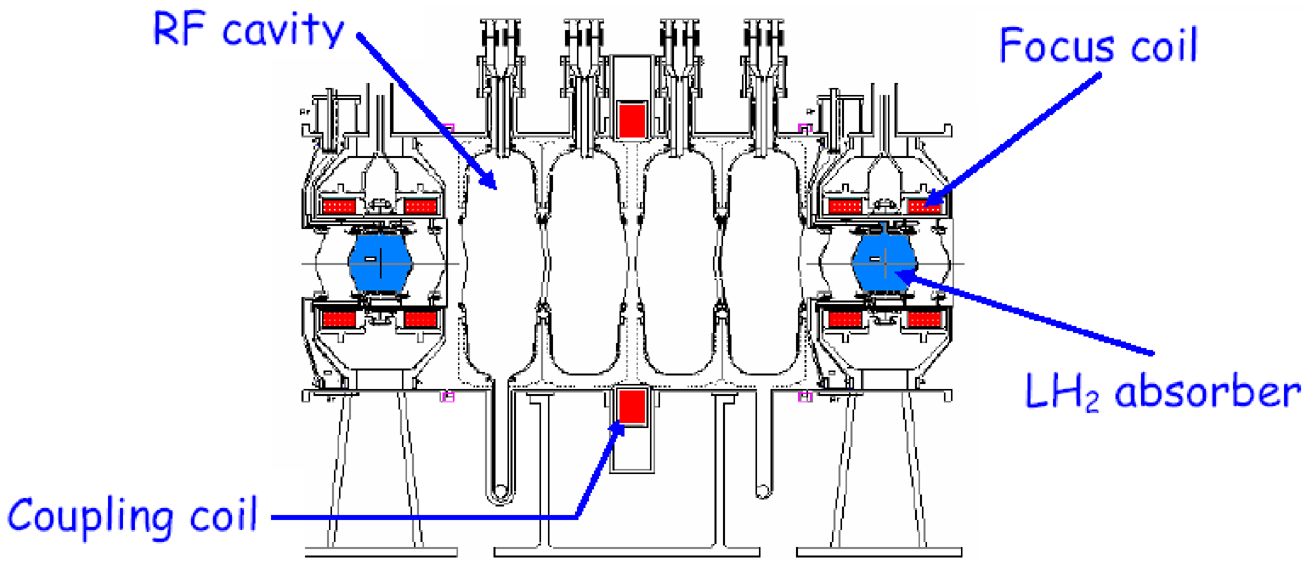


- Cooling competes with Coulomb Scattering
- Best with Hydrogen
- and Strong Focus

Cooling Performance in Study IIa



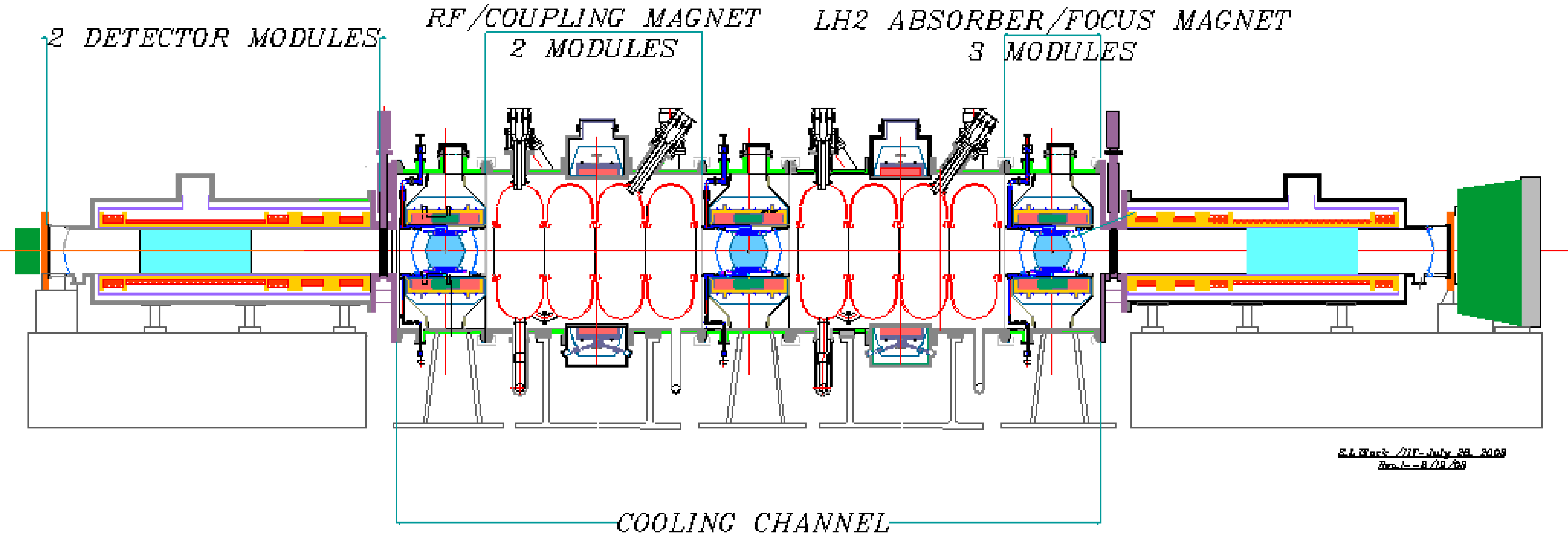
R&D on Ionization Cooling Components
MUCOOL Collab Lead by Fermilab (A. Bross)



- Design, Build, Absorbers
- Design, Build, and Test Absorber Windows
- High Gradient RF Studies at 805 MHz (Lab G FNAL)
- Design & Start Const. of 201 MHz Cavities
- Experiment with High Pressure Hydrogen STTR
- Test area at FNAL

MUON IONIZATION COOLING EXPERIMENT (MICE)

- Solid Design based on Study-2 channel
  (Similar components to RFOFO cooling ring)
- International Collaboration: (US, Europe, Japan)
- Approved at RAL and funded for Phase I

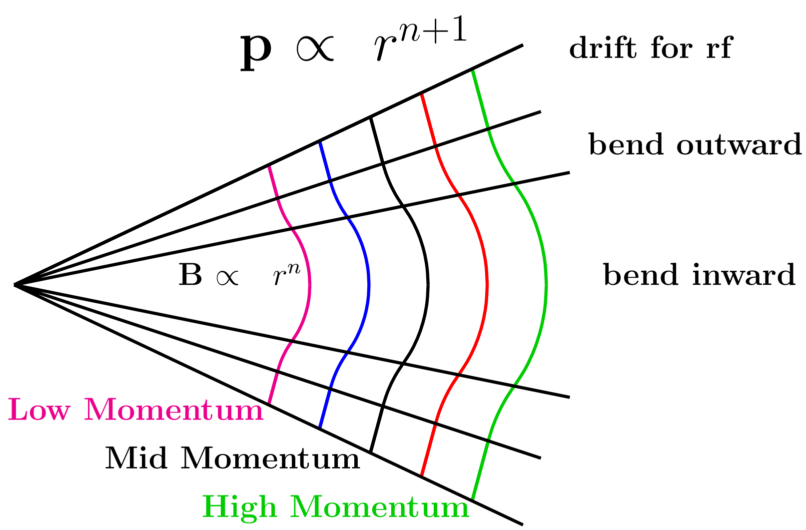


4) Acceleration

- Must be fast: Muon lifetime=2 micro sec

- Use initial SC Linac
- Then Recirculating Linear Collider (RLA)
- Followed by FFAG's

a) Scaling FFAG MURA & KEK (Japan)



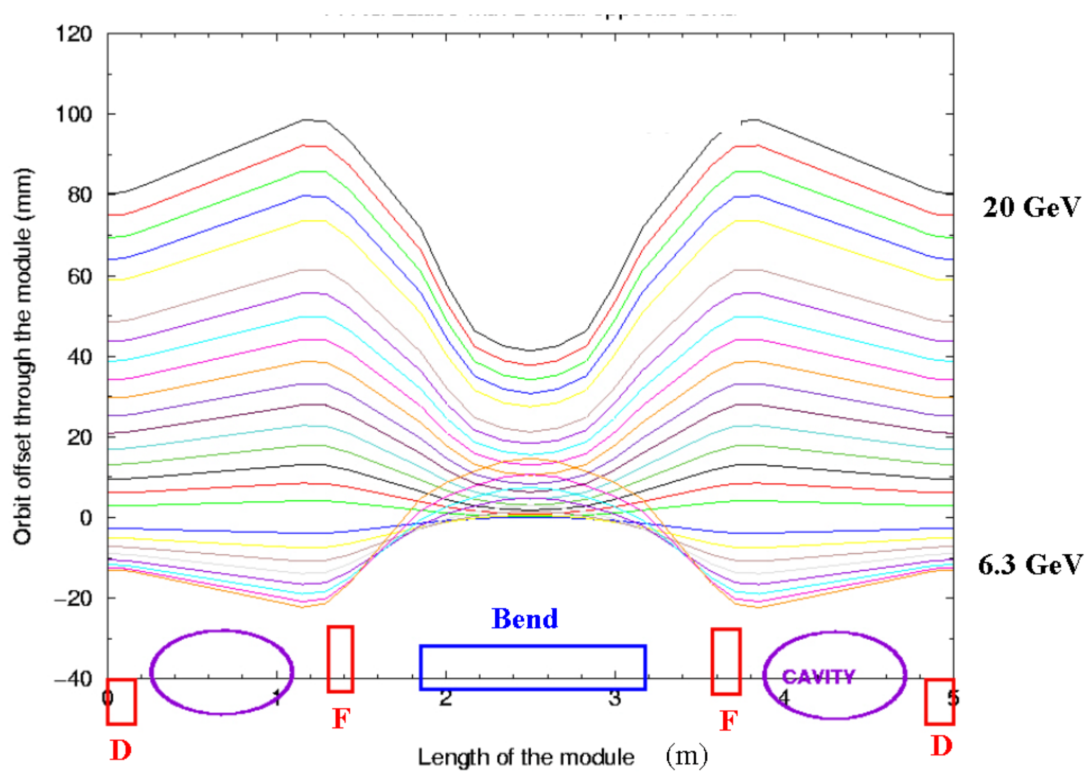
- Eliminates multiple arcs of RLA
- Allows more turns → less RF
- Δp limited only by aperture but only 1:2 for Japan 20 GeV
- Tune independent of momentum i.e. Chromaticity=0

BUT

- Large magnet apertures
- Non-isochronous
  → Low Frequency RF
  → Non-superconducting RF

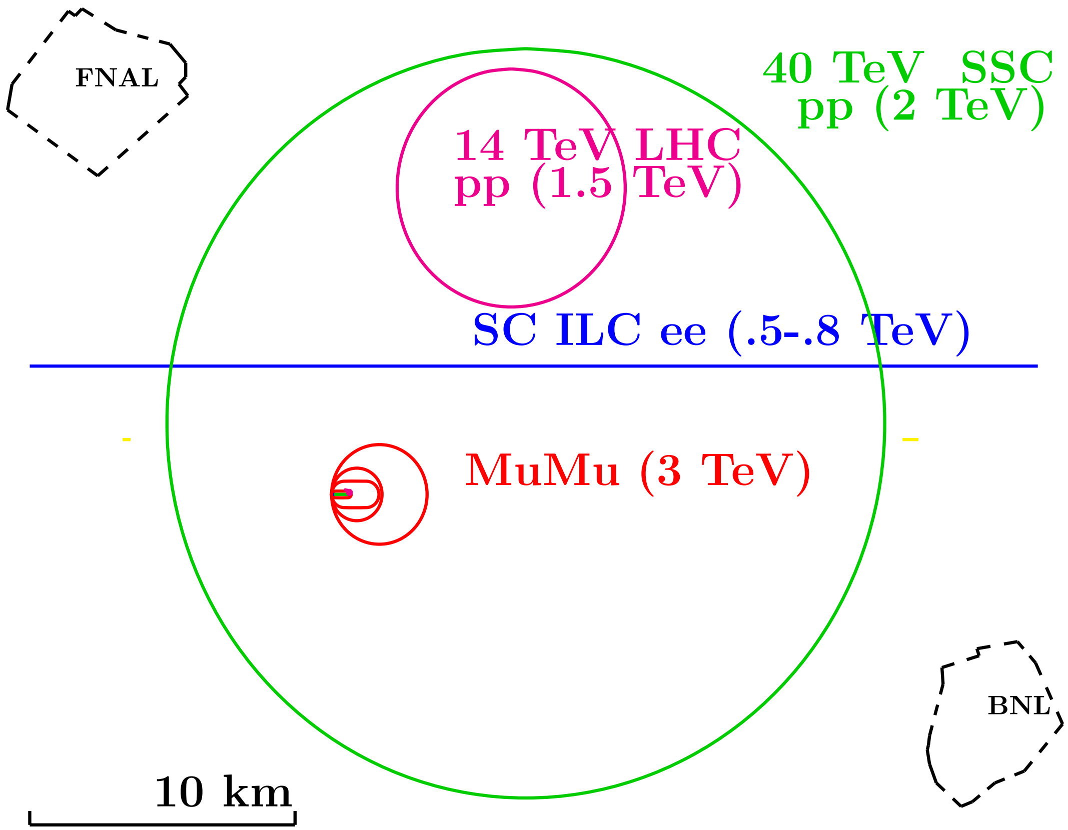
b) Non-Scaling FFAG (Proposed by Carol Johnstone)

Combined function strongly focusing lattices without sextupoles
e.g. from Dejan Trbojevic



- Orbits are not similar
- They are closer together than in scaling
  - $\longrightarrow$ smaller apertures
  - $\longrightarrow$ more isochronous

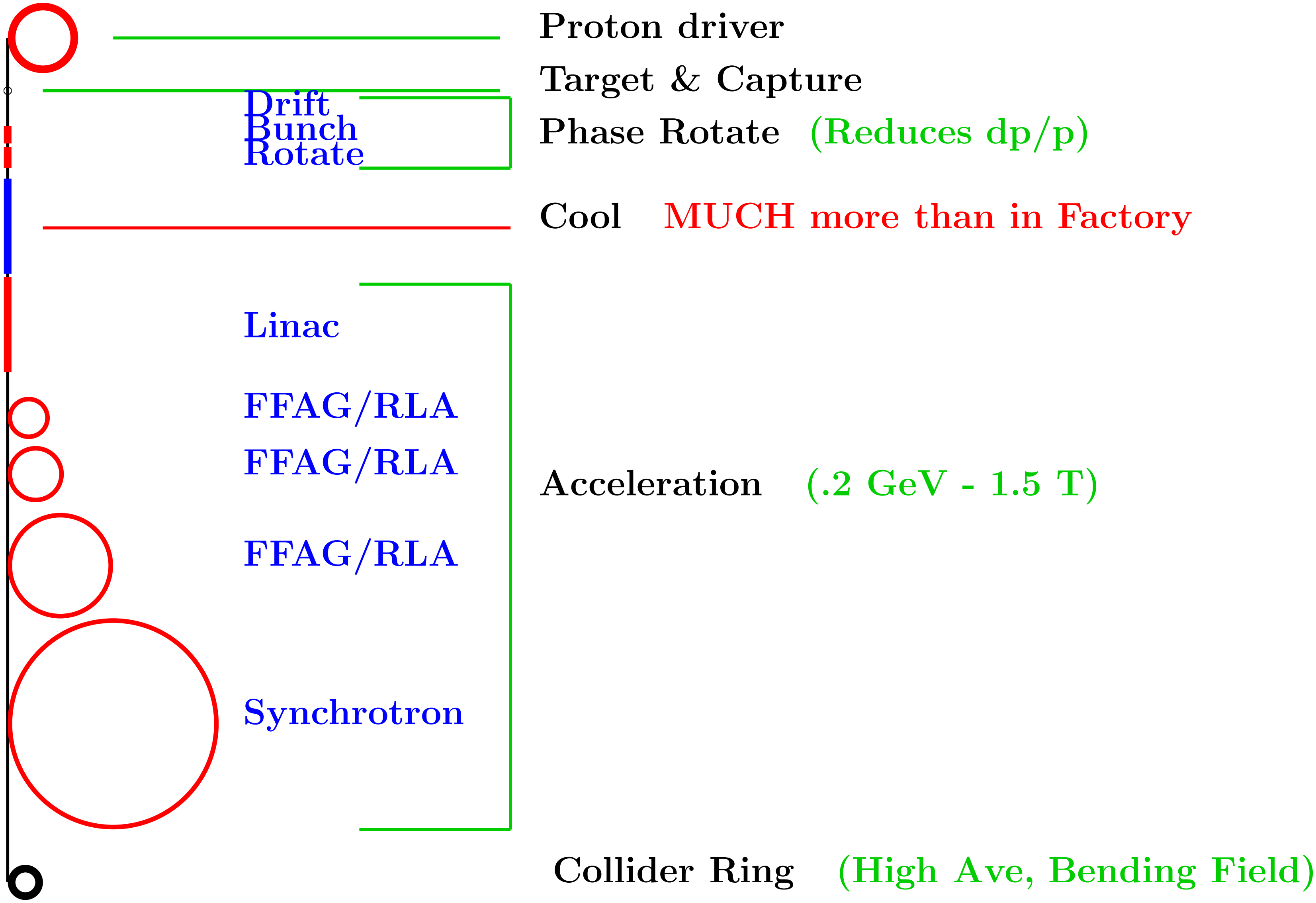
Why a Muon Collider



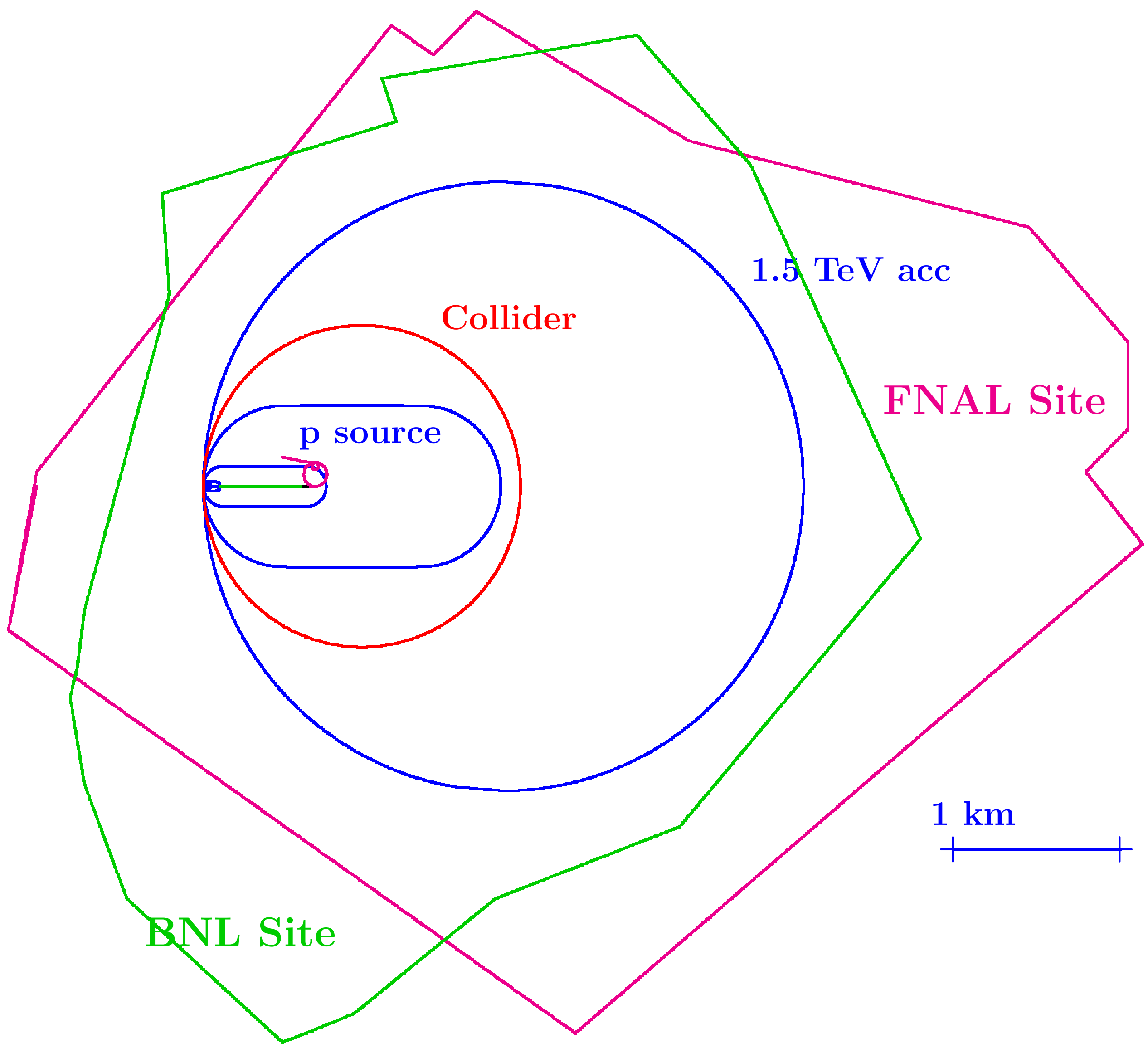
- Muons are point like, similar to electrons
- Can probe the same physics, and some more
- But have 40,000 less radiation
- So Muon Colliders can be much smaller than Linear Colliders

Schematic of Muon Collider (not to scale)

Injection in both directions in all rings (not shown)



3 TeV Muon Collider (drawn to scale)



Snowmass 98 Assumed

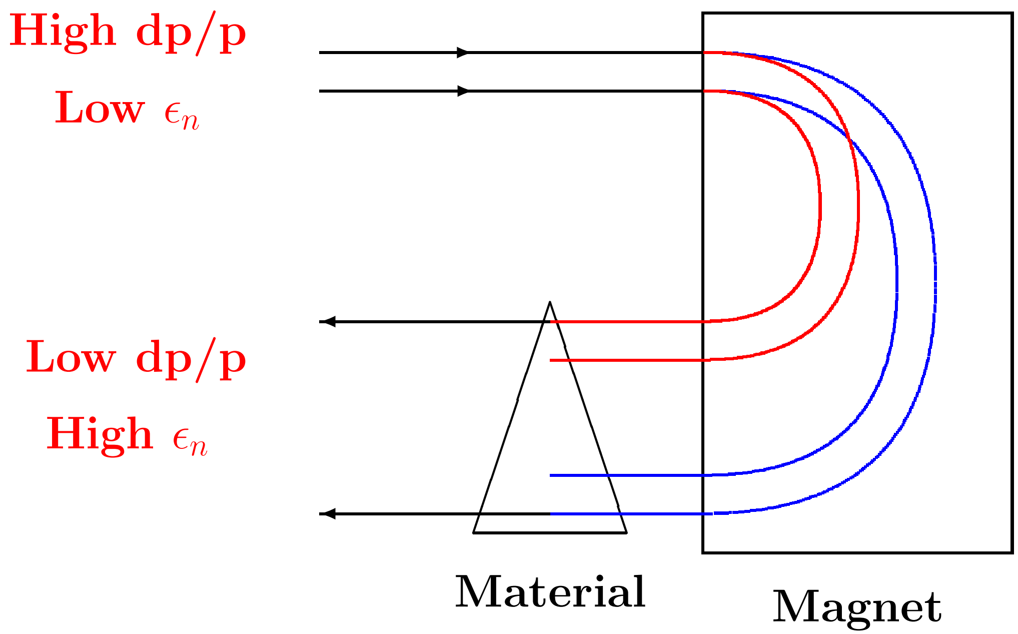
Average bending field	**T**	**5.2**
Tune Shift (from e rings)		**0.044**
Luminosity	$10^{33} cm^{-2}$	**70**

	$\mathbf{E_{cm}}$ TeV	$\mathbf{N_\mu}$ 10^{12}	**f** Hz	$\mathbf{P_\mu}$ MW	$\beta_\perp = \sigma_z$ mm	**dp/p** %	**emit**$_\perp$ π mm	**emit**$_\parallel$ π mm
Required	3	2	30	28	3	0.16	.05	72
Initial							20	2000
Factor							400	30

Required Cooling 6 D by 1/6,000,000

And Cooling must include Longitudinal: i.e. dp/p

Longitudinal Cooling: Emittance Exchange

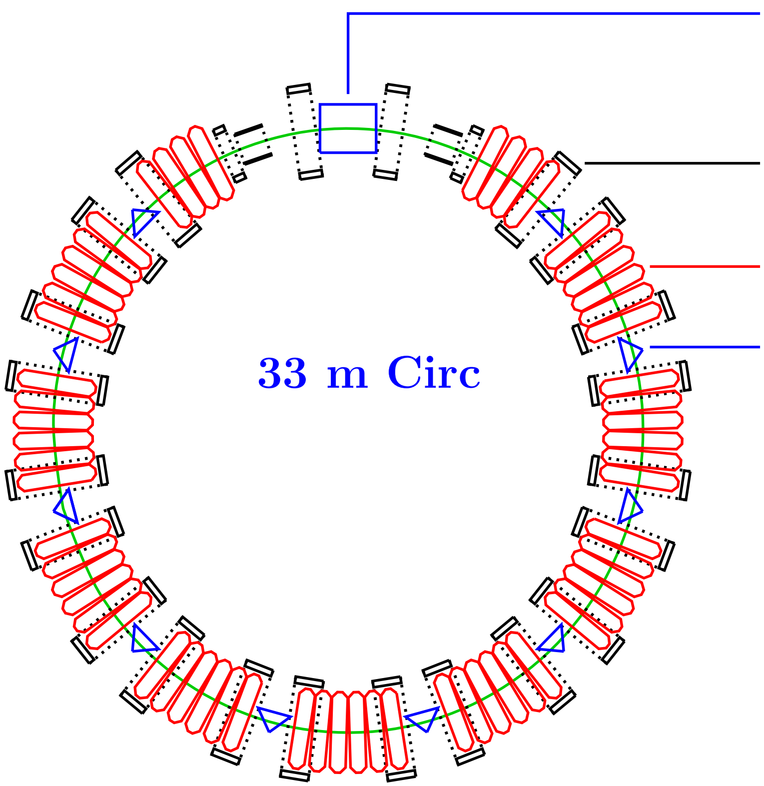


- **dp/p (and Longitudinal emittance) reduced**
- **But σ_y (and transverse emittance) increased**
- **Transverse cooling from mean loss in absorber**
  $\longrightarrow$ "Emittance Exchange"
- **J's are modified, but Jx + Jy + Jz = constant**

"Emittance Exchange" + Transverse Cooling = 6 D cooling

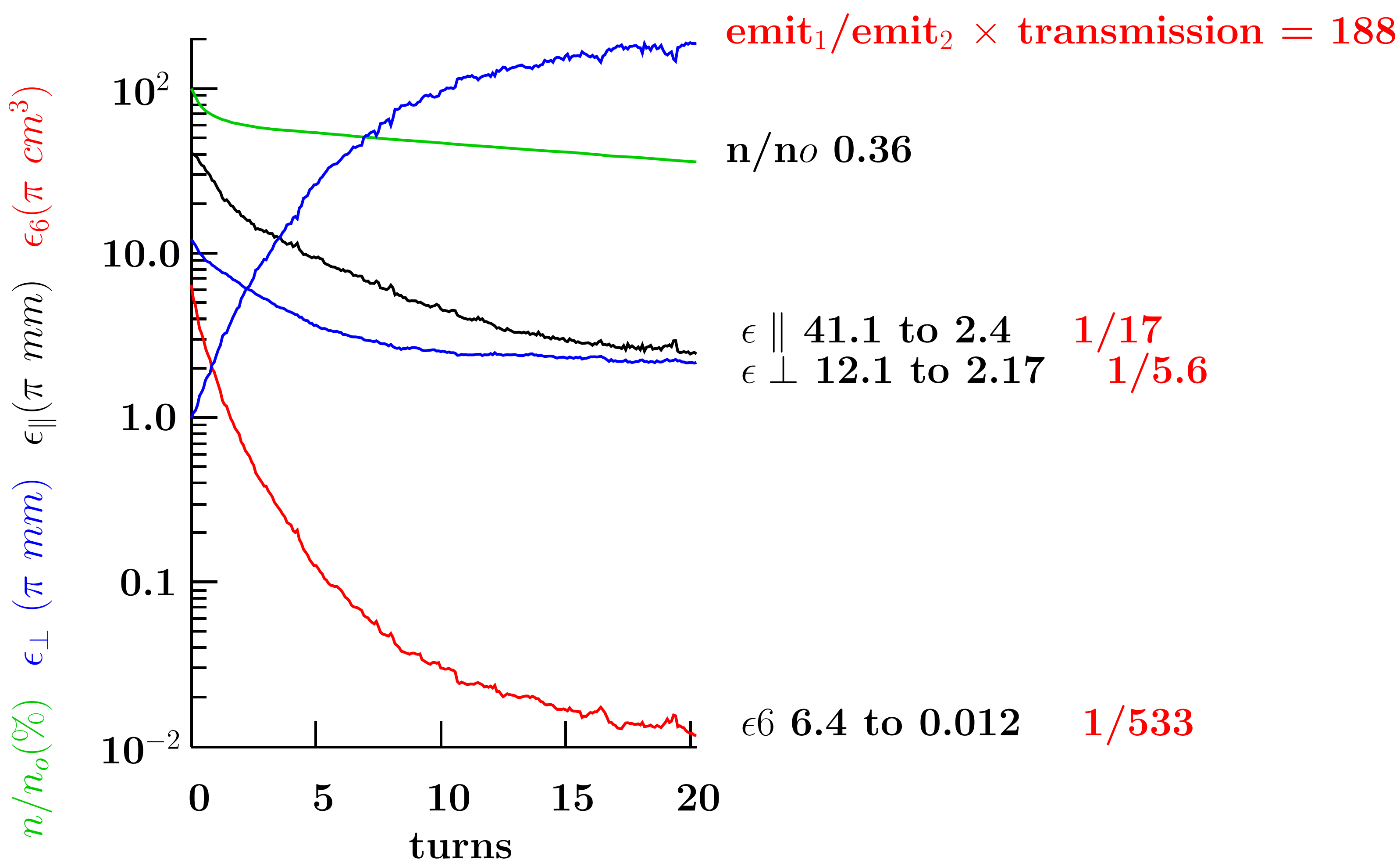
e.g. 6 D cooling in "RFOFO" Ring with Wedges

- Bending gives dispersion
- Wedge absorbers give cooling also in longitudinal
- Many turns in ring gives more cooling at lower cost
- But Injection/extraction Hard



- Could be converted to Helix
- Avoids injection/extraction
- Better performance by tapering
- But more expensive

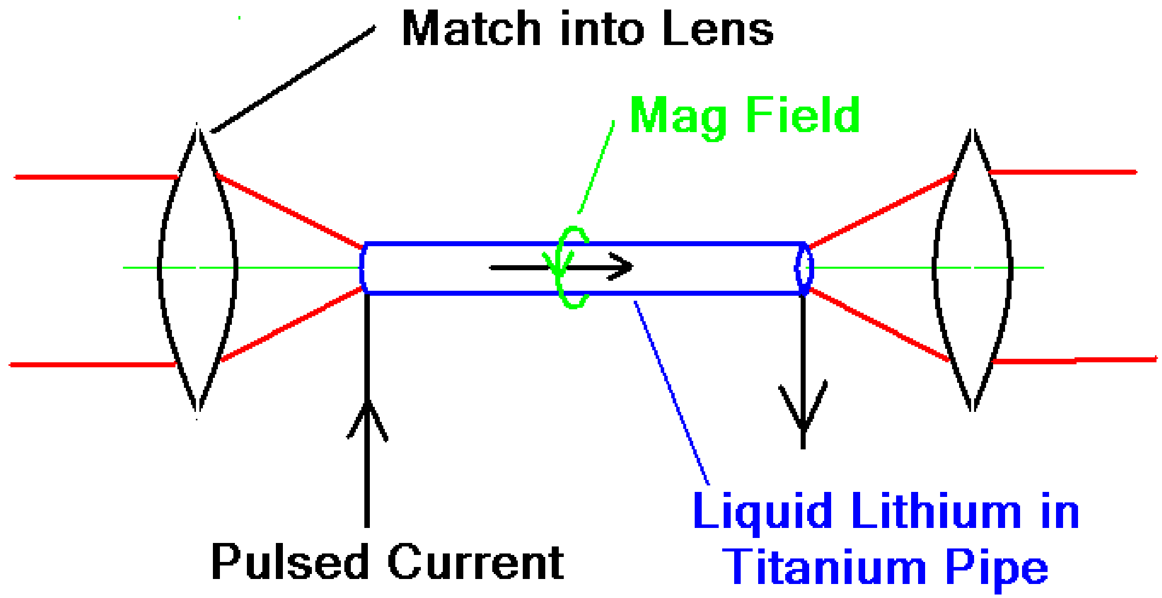
Performance of RFOFO Ring



- **Final Long Emittance 2400 (pi mm mrad)**
- **Less that (7200 pi mm mrad) Required for Collider**

Final cooling to very low emittance

Lithium Lens



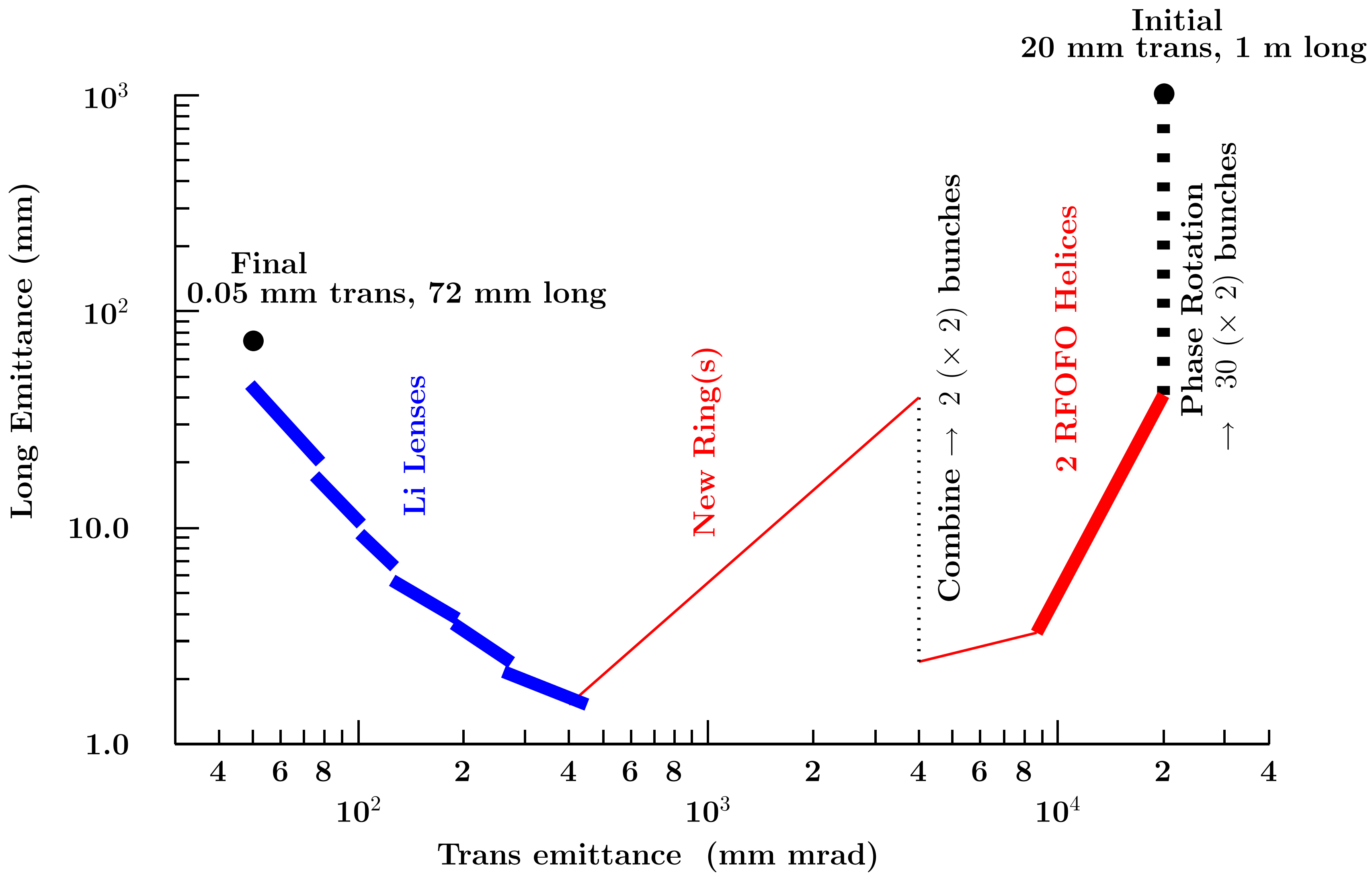
- For uniform i then perfect lens

$$I \propto r^2 \qquad\qquad \text{Bending} \propto B \propto I/r \propto r$$

- Maximum current limited by breaking containment tube
- Pressure $\propto$ Surface Field Current lenses 10 T

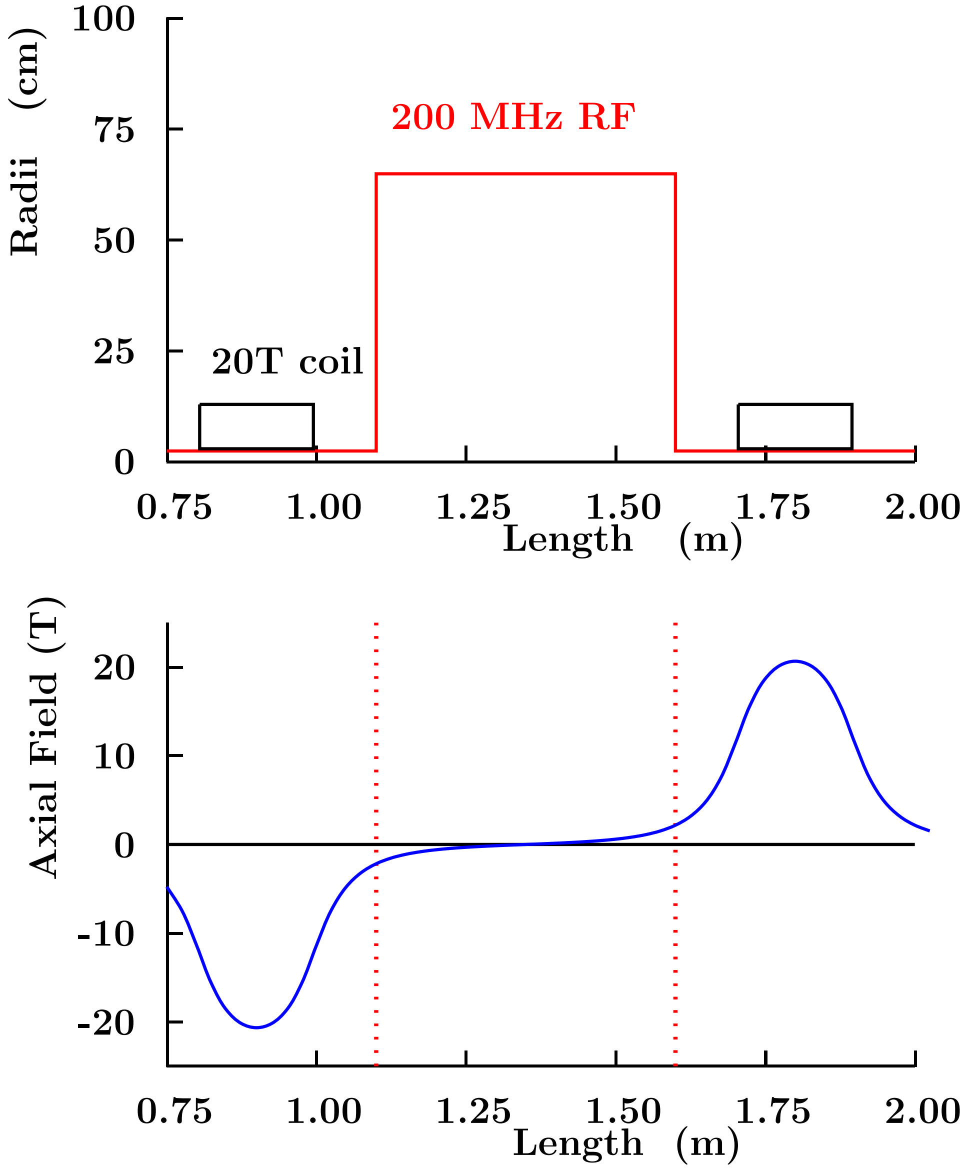
Plausible Solution to Collider Requirements

Heavy lines indicate completed simulations



Alternative to Li Lenses for final cooling

One Cell of HTS 20T Cooling Lattice



- Magnets are small
- RF is in low field

- Not yet simulated

Conclusion

- **Neutrino Factory**
  - **If $\theta_{13} < 10^{-2}$ Factory is only hope to see CP**
  - **If $\theta_{13} > 10^{-2}$ Factory perhaps not needed**
  - **Will not know for 5-10 years**
  - **International Scoping Study (ISS) ongoing**
- **Muon Collider**
  - **Interesting for physics & Smaller than Linear Collider**
  - **Difficult technically**
  - **Neutrino Radiation limits Maximum Energy**
  - **New progress on design**
- **Sound R&D Program in Progress**
  - **Hg Jet Target for 4 MW (CERN Exp)**
  - **Cooling Components (MUCOOL)**
  - **SC RF at 200 MHz (Cornell)**
  - **Cooling Experiment (MICE)**
- **Interesting Spin-Offs: Hg Target, Non-Scaling FFAG's**